

DMX Dimmer

for semi-professional applications

Design by A. Kneer

Using a digital DMX signal, a 0-10 V control voltage or manual control, this dimmer can individually set the brightness of up to four spotlights, each of which may present a load of up to 1 kW.



The DMX Dimmer described in this article is aimed at the semi-professional application area. It is operated using a light-mixing panel (digital DMX or analogue). It can dim lights (and it does this in an outstanding manner), but it intentionally lacks non-essential frills such as a built-in running-light display or sound-to-light control. Instead, it features optional lamp preheating (with an adjustable range of 0-100% brightness) for gentle lamp operation and it can be used in stand-alone mode, at a fixed dimming level, without a light-mixing panel. Features such

Features

- compatible with DMX-512 and 0-10 V light-mixing panels
- convenient channel selection using thumbwheel switches
- maximum connected load: one 1000-watt spotlight per channel
- phase-controlled dimmer for (halogen) incandescent lamps using triacs
- linear lamp control using digital characteristic curve correction for the phase angle
- configurable lamp preheating: 0 to 100 %
- compact construction and simplest possible mounting on spotlights, light masts or traverses
- robust, interference-immune design

as simple channel selection using thumbwheel switches and digital linearisation of the control range round out the concept.

In lighting technology, spotlight bars with four or six spotlights are common. In order to keep the dimmer featured here simple and compact, it has been designed for single-phase operation. If we assume 1 kW per spotlight, three spotlights can be connected to a 16-A circuit. A 6-light bar thus requires two dimmers with three channels each. In order to allow the dimmer to be fitted next to the spotlights, a metal enclosure in the form of a somewhat oversized three-way mains power bar has been developed. The enclosure also acts as the heat sink for the triacs.

Since decoding the DMX signal anyhow requires the use of a microcontroller, all of the dimming functions are largely implemented in software. The 68HC11F1 microcontroller used here contains 1 kB of internal RAM and 512 bytes of internal EEPROM, and the software has been squeezed into this memory to avoid using an external ROM. This saves space and money. An extensive range of integrated peripheral functions, such as a serial interface and A/D converter, combined with the timer structure of the processor, allows the circuit and the software to be kept very compact.

The block diagram (Figure 1) shows the software functions. The software is split into three different tasks having different priorities.

The DMX task

DMX-512 is increasingly supplanting the 0-10 V analogue signal that was previously common. The DMX-512 protocol is electrically identical to RS485, so all types of RS485 line drivers can be used. Using a two-wire cable, the control unit sends data frames (each containing eight utility bits) at a rate of 250 kbit/s. The data can be decoded in the receiver using a UART interface connected to a processor. A DMX data frame contains 11 bits (including the start bit and two stop bits) and thus has a transmission time of typically 44 μ s. The DMX standard specifies that the data bytes may be sent with a maximum spacing of 1 s. However, no

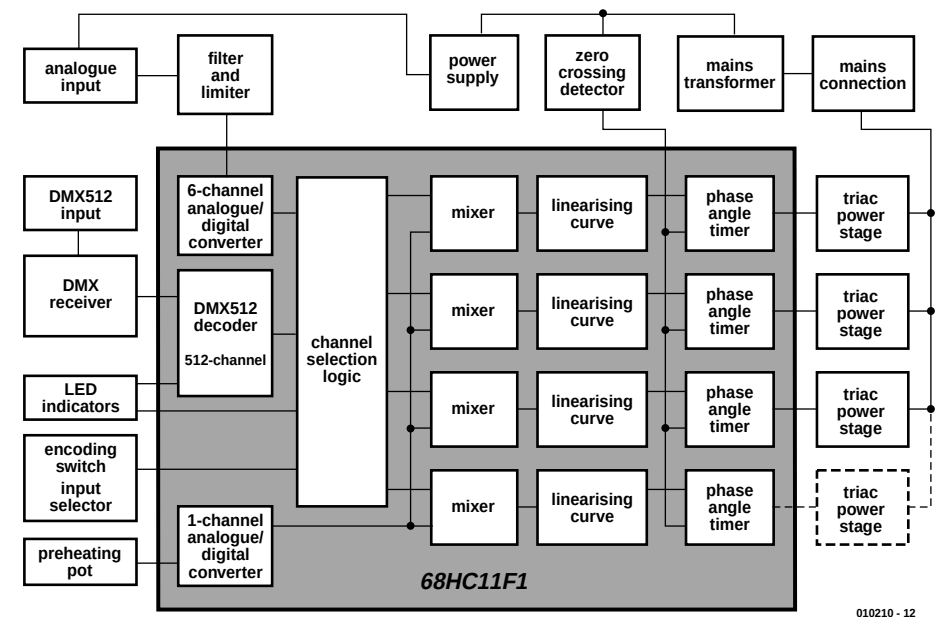


Figure 1. Block diagram of the DMX Dimmer.

minimum spacing is specified. If a DMX receiver is to work with all types of transmitters, it must be able to process all of the data frames, regardless of their time separations. If the light-mixing panel is very fast and sends successive frames without any delays, the microcontroller is left with only the frame time of 44 μ s for processing the data. This requires a high-performance processor and optimised software.

The DMX transmitter starts the transfer with a Break (a Low level on the DMX+ line lasting at least 88 μ s). This 'rule violation' allows the receiver to recognise the start of the transfer. Next, the transmitter sends the start byte, which indicates the target device for the data. DMX dimmers may only respond to data beginning with the start byte '0'. The start byte thus makes it theoretically possible to transfer data for 512 dimmer channels in addition to 512 scanner channels, 512 moving-light channels and so on. However, this option is seldom used.

After the start byte, the transmitter starts to sequentially send the data for the individual channels. The final channel to be sent may be channel 512, but this is not mandatory. The sequence may be terminated earlier by sending a Break. You will find more information about the DMX512 transfer modes in the May

2001 issue of *Elektor Electronics*.

The DMX handler in the software, which complies with the DMX512/1990 standard, reads all 512 channels (if the start byte is '0') and stores the values in the RAM. Since the DMX handler has only 44 μ s to do its job, this task is assigned the highest priority in the system. The DMX handler is called as soon as a byte has arrived in the UART receive buffer.

The main task

The main routine of the software evaluates the settings of the controls and drives the light-emitting diodes. The input signals for the dimmer originate either from the internal A/D converter, which receives analogue signals via the 8-way DIN socket commonly used for technical lighting, or directly from the DMX channel data. Depending on the setting of the channel selection switches, the selection logic picks out three of the six analogue channels or three DMX channels and retrieves their brightness values from the A/D converter or the DMX intermediate storage registers. Following this, the values are compared with the brightness values for lamp preheating, and the larger of each pair of values is converted into an 'on'-time control value for the associated triac using a linearisation formula.

Since the mains voltage is sinusoidal rather than being a square wave, the amount of power supplied to the lamp is not proportional to the phase angle setting (see Figure 2a). In order to allow the brightness of the spotlight to be precisely set using the light-

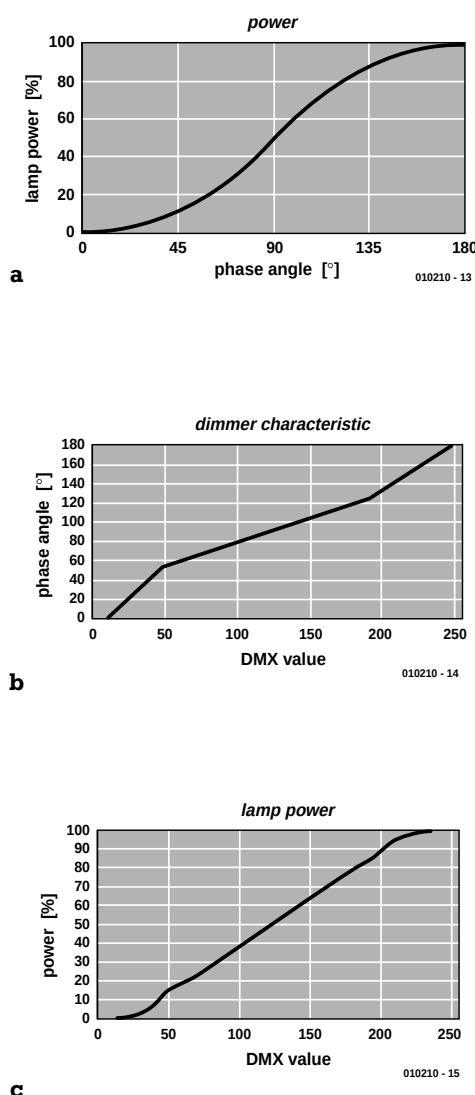


Figure 2. a) lamp power versus phase angle; b) the software uses this curve to linearise the power; c) the result of the linearisation: a linear response with 'flat' portions for low and high DMX values.

mixing panel, even for small values, a linear control characteristic is desirable. In order to achieve this, the dimmer has an inverse characteristic (Figure 2b).

The control characteristic of the dimmer is 'flat' at the upper and lower ends of the curve. This is important for analogue mixing panels in order to prevent a few millivolts of residual voltage from causing the lamps to be illuminated as well as to avoid not being able to achieve 100% brightness. The characteristic curve correction yields a nearly linear characteristic curve for power versus digital value (Figure 2c). The result from the characteristic curve correction, which is the value for the duration of the 'on' time, is then written to the timer register of the microcontroller.

The timer task

The triacs are driven using the 68HC11 output-compare registers. The Timer task is called on each zero crossing of the mains voltage. When the Timer task is called, the current value of the free-running 68HC11 counter (clocked at $1\ \mu\text{s}$) is temporarily stored, following which the phase angle is added to this value and stored in the output-compare register. After this, the stored value is continuously compared with the current counter value without any involvement on the part of the software. If the counter value is equal to the value in the output-compare register, the triac is energised. The triac is de-energised by the Timer task at the next zero crossing. As a result, a PWM signal synchronised to the mains frequency appears at the 68HC11 output.

Analogue and DMX inputs

At the upper left of the schematic diagram (Figure 3) you will see the power supply for the low-voltage portion of the circuit. Fuse F2 is a temperature-sensitive fuse. If the air temperature inside the enclosure becomes greater than $95\ ^\circ\text{C}$ for whatever reason, this fuse switches off the dimmer forever. Note that the $95\ ^\circ\text{C}$ value also applies to soldering, so be careful when assembling the circuit!

The supply voltage for an analogue mixing panel is also tapped off from the regulator, separately fused by F3 (a Polyswitch fuse, or more precisely a PTC thermistor) and fed out via the DIN socket. This also makes it possible to connect a very simple 'mixing panel' consisting of only a 10-V voltage regulator and a potentiometer.

The rectified secondary voltage is tapped off from the anode of D1. Since D1 'isolates' smoothing capacitor C16, the zero crossings of the AC voltage that are important for the timer are also present at this point. The zero crossings are detected by a comparator circuit using IC4. The actual comparator, IC4a, is provided with hysteresis by R21. This is because dimmers are often adversely affected by momentary

dropouts in the mains voltage resulting from the effects of lead inductance and resistance when a heavy load is switched near the zero crossing, which the zero-crossing detector incorrectly interprets as zero crossings. The hysteresis minimises this problem. IC4b buffers and inverts the output signal so it can be applied to the interrupt input of the microcontroller.

A network consisting of anti-parallel dual diodes (D3–D6), two Schottky diodes (D10 and D11), capacitors C9–C14 and several resistors (R28–R33, resistor array R46 and R45) forms the six-channel analogue input for the dimmer. Each of the six channels is wired identically. The protective resistors form voltage dividers that reduce the input voltage range of 0–10 V to a range of 0–5 V. Together with the capacitors, the voltage dividers form RC filters that eliminate HF noise voltages. The dual diodes limit any excess positive or negative voltages that may be present. Each of these diodes is connected to the 4.7-k Ω resistor R45 and one of the two Schottky diodes (D10 or D11). Due to the voltage drops of the Schottky diodes, the voltages present at R45 are approximately 0.3 V and 4.7 V (with respect to ground). This means that the voltage at the microcontroller inputs cannot be greater than 4.7 V plus one diode threshold voltage (5.4 V in total) and cannot drop below $-0.4\ \text{V}$ ($= 0.3\ \text{V} - 0.7\ \text{V}$). On the circuit board, the inputs are connected to a header strip that in turn is connected to the previously mentioned 8-way DIN socket, as shown in Figure 4. The RC low-pass filter formed by R43 and C16, which provides a noise-free 5-V reference, also belongs to the A/D converter.

The DMX-512 input is built around an LTC485, a bi-directional RS485 line driver. The transmit function is not used here and is disabled. The input lines are fed to the IC via a low-pass filter that eliminates HR noise. The output of the receiver is connected directly to the serial interface of the 68HC11. The wiring between K3 and the DMX connectors is shown in Figure 5.

Three LEDs are driven by microcontroller port pins PD5–PD8 via transistor driver stages to indicate

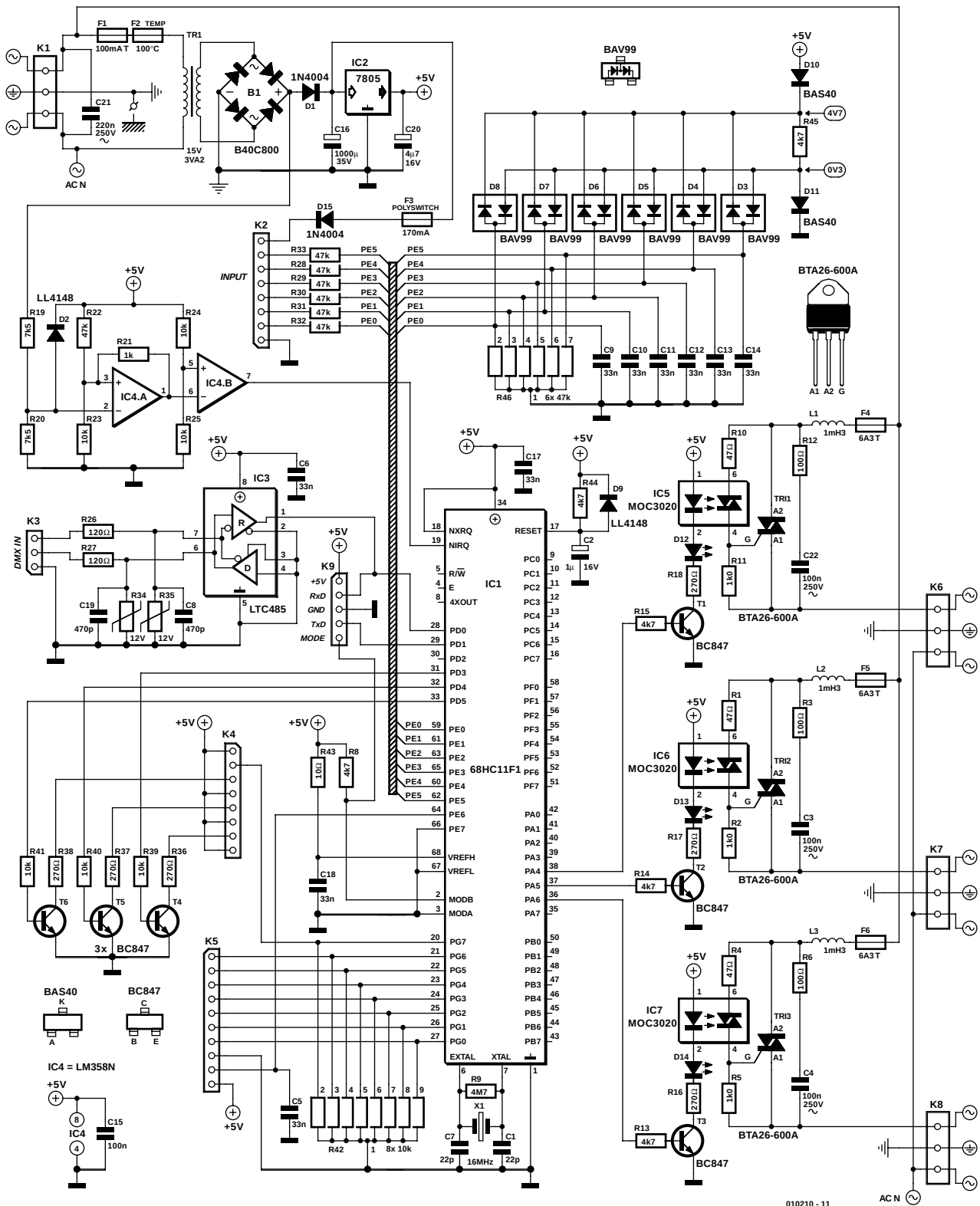


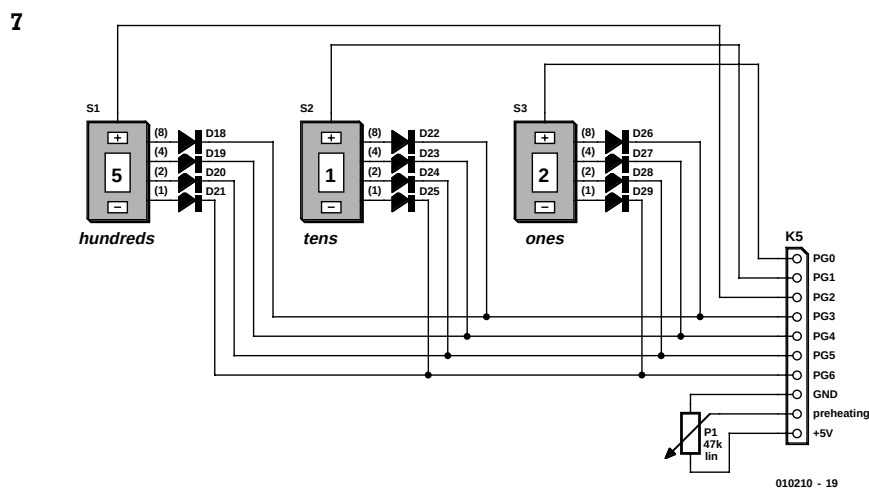
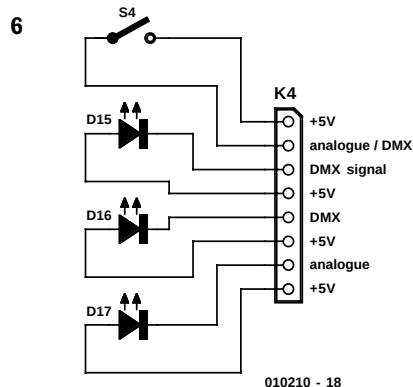
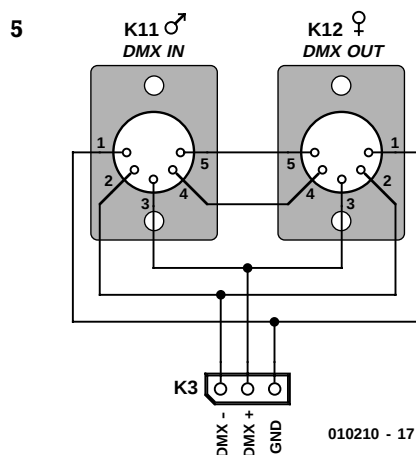
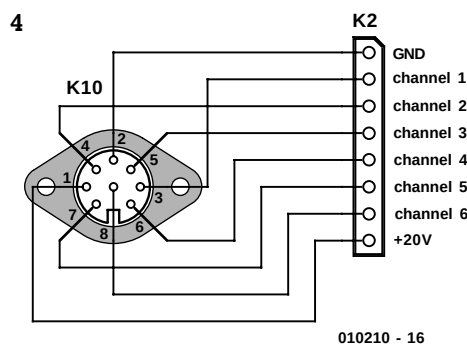
Figure 3. The schematic diagram, showing the inputs on the left and the power electronics on the right. The microcontroller that mediates between the two is shown in the middle.

whether the DMX or analogue input is active. These LEDs are connected to K4 along with the DMX/Analogue selector switch. The switch position is read via port PG7. The wiring

between K4 and the LEDs and switch is shown in **Figure 6**.

The channel-select thumbwheel switches are connected via K5 (see **Figure 7**). These switches have

binary outputs that are wired in parallel after being isolated by external 1N4148 diodes connected directly to the outputs. To evaluate the switch positions, the microcontroller multiplexes the three switches via PG0–PG3 and



recognises the set values via port pins PG4-PG6.

The analogue channels are also affected by the thumbwheel switches. If channel 1 is selected, the control voltage on PE0 determines the brightness of the lamp connected to PA6, the voltage on PE1 regulates PA5 and the voltage on PE2 regulates PA4. If channel 2 is selected, PE1 regulates PA6, PE2 regulates PA5 and so on.

The pot for setting the preheating level is connected to the remaining pins of K5. The wiper of the pot is connected directly to the ADC input of the microcontroller (PE6). A capacitor connected in parallel eliminates potential noise.

Outputs

The processor itself needs no additional circuitry except for the 16-MHz oscillator and the reset circuit (R44, C2 and D9). Resistor R8 connected to MODB ensures that the processor starts up in single-chip mode following a reset. We can thus concentrate our attention on the power outputs.

The three triac output stages are connected to PA4-PA6. The same circuit is used for each output stage.

A type BTA26-600A triac is used here. It is specified for a maximum current of 26 A, which may appear to be overdimensioned, but it must be borne in mind that an incandescent lamp has a very low cold resistance and thus a correspondingly high inrush current (up to ten times the rated current). Besides this, some halogen lamps have the unpleasant

property of producing a short circuit when they burn out. The more robust the triac, the higher the probability that it will survive a lamp failure. Compared with the widely used TIC type, the BTA type used here has the advantage that its case is insulated from its leads, so it is not necessary to use elaborate insulation hardware. Each triac is driven by a second triac integrated into an optocoupler. As soon as the microcontroller sets its output High, the attached transistor conducts and current flows through the LED in the optocoupler. The triac in the optocoupler then fires and current flows from the 'live' mains lead to the gate of the power triac. This triac fires in turn, short-circuiting the path via the optocoupler and allowing current to flow through the lamp.

Depending on the switch-on phase angle, it can happen that the full mains voltage is suddenly applied to the lamp, which leads to a correspondingly steep rise in current. However, steep current rises are undesirable from an EMI perspective. In order to limit the steepness of the rising edge, a coil is connected in series with the lamp. This coil is also the component that limits the power capacity of the dimmer to 1 kW per lamp, since its maximum allowable current is 4.5 A.

During switch-on the voltage across the triac undergoes a step change, and this can create interference. In order to reduce this, a RC network is connected across the triac. This network also isolates the triac from voltage peaks, such as those that occur when an inductive load is switched off, and thus prevents false triggering.

In spite of these measures, voltage and current peaks are still generated, and in order to minimise the amount of noise from these peaks that is fed back into the mains network, a 220-nF capacitor is connected across the mains leads at the mains input. This noise-suppression capacitor must be an approved X-type capacitor.

Assembly

In order to keep the dimmer compact, SMD components (0805 outline, or if necessary 1206) are used for the

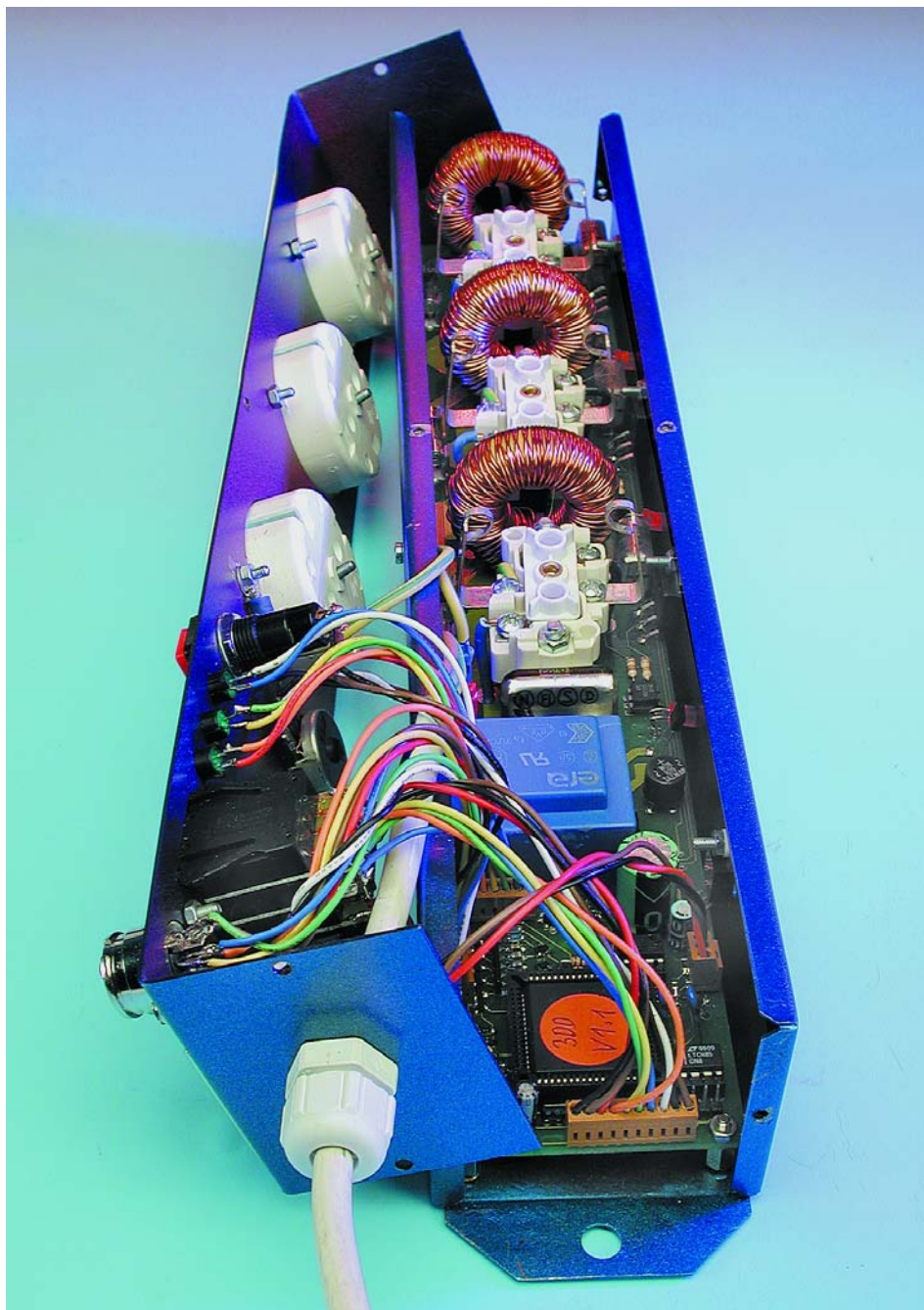
Figures 4–7. The connections between the controls and indicators and the circuit board.

control portion of the circuit. The SMD transistors and diodes specified in the components list are not critical (but be careful with D10 and D11), and they can certainly be replaced by similar components having the same lead arrangements. When fitting the components to the double-sided printed circuit board (shown at slightly reduced scale in **Figure 8**), it is best to start with these components. After they are fitted, all of the other components can be fitted, working from the smallest to the largest. When fitting the temperature-sensitive fuse, you must take care not to set it off. Soldering SMD components is a rather fussy process that is best performed under the watchful eye of a magnifying lamp.

The triacs (as well as the voltage regulator) must be cooled. The simplest solution is a metal enclosure. However, you will search in vain for a suitable ready-made enclosure in the electronics catalogues, so for better or worse it must be a DIY item. The best approach is to take inspiration from the small aluminium cases produced by Teko, which are easy to bend. The holes in the lid for the outlets can be cut to fit using a fretsaw, and in addition, as shown in the title picture, you will have to make holes for the three connectors, the thumb-wheel switches, three LEDs, the Analogue/DMX selector switch and the pot. Drill the fastening holes for the triacs (as well as the associated LEDs) along one side, together with hole for fastening the voltage regulator. In contrast to the triacs used here, the voltage regulator may not be insulated from the case (using a mica washer, for example).

When you have finished machining the enclosure, set the partly finished printed circuit board into the enclosure and tack the voltage regulator and triacs to the top side of the circuit board using a drop of solder after first firmly screwing them to the enclosure. They can be properly soldered afterwards. This prevents mechanical stresses from arising.

The circuit board tracks passing underneath the coils must be insulated from the coils by sticking pieces of insulating tape on top of them. Attach the coils using cable ties and a bit of hot-melt glue and



then solder their leads in place. Fit the earthed mains outlets on 15-mm standoffs so that each outlet stands above a coil. Clamp lengths of copper wire with a diameter of 1.5 mm to the terminals of the sockets, pass them through the holes in the circuit board and solder them in place.

Safety

Now we come to the subject of electrical safety. Whenever you are dealing with electronics working at the mains voltage, and in particular in the case of a Class-I device with a

metallic enclosure, the circuit board layout is especially important. A certain separation (3 mm) must be maintained between components carrying mains voltage and the circuit board tracks or the enclosure. Furthermore, all exposed metallic parts of the enclosure and all metallic parts leading to the outside, such as metallic knobs, must be securely tied to the protective earth lead. The circuit ground in the low-voltage part of the circuit is also connected to the protective earth lead (PE). Although 'Schuko' type mains sockets are shown in the photograph, UK readers should use 13A panel mount appliance sockets complying with BS1363 **only**. Do not use non-insulated triacs, since although it would

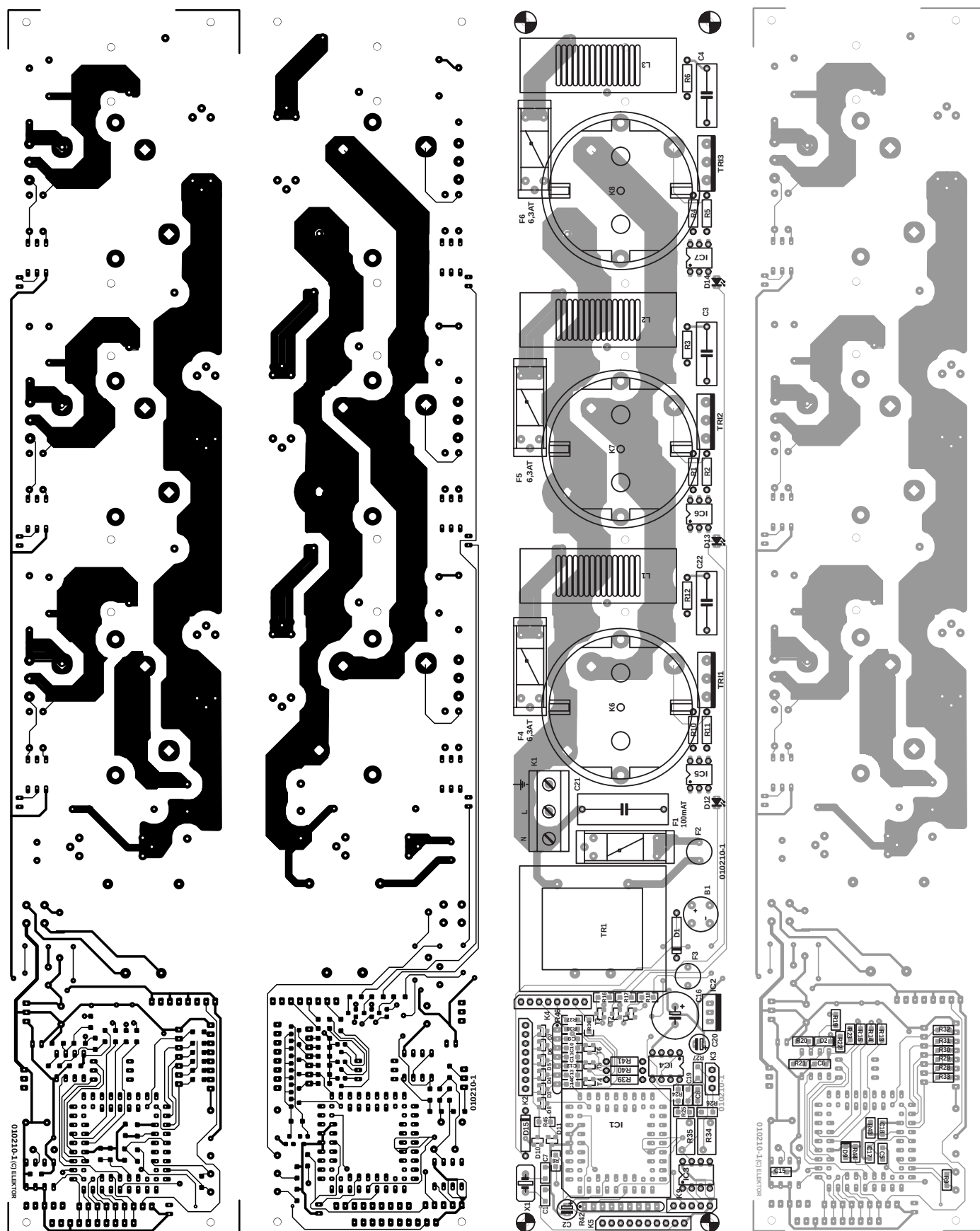


Figure 8. Everything on a single printed circuit board: the component layout and track layout for the dimmer circuit board at a scale of 1 : 1.5.

COMPONENTS LIST

(all SMD devices are size 0805)

Resistors:

R1,R4,R10 = 47Ω
R2,R5,R11 = 1kΩ
R3,R6,R12 = 100Ω
R7 = not fitted
R8,R13,R14,R15,R44,R45 = 4kΩ
SMD
R9 = 4MΩ
SMD
R16,R17,R18 = 270Ω
SMD
R19,R20 = 7kΩ
SMD
R21 = 1kΩ
SMD
R22,R28-R33 = 47kΩ
SMD
R23,R24,R25 = 10kΩ
SMD
R26,R27 = 120Ω
SMD
R34,R35 = 12V Varistor K14/I2
R36...R38 = 270Ω
R39...R41 = 10kΩ
R42 = 8-way 10kΩ SIL array
R43 = 10Ω
SMD
R46 = 6-way 47kΩ SIL array

Capacitors:

C1,C7 = 22pF
SMD
C2 = 1μF 16V radial
C3,C4,C22 = 100nF 250VAC, Class X2
C5,C6,C9,-C14,C17,C18 = 33nF
SMD
C8,C19 = 470pF
SMD
C15 = 100nF
SMD
C16 = 1000μF 35V radial
C20 = 4μF 16V radial
C21 = 220nF 250VAC Class X2

Semiconductors:

B1 = B40C800 bridge rectifier, round case (40V piv, 800mA)
D1,D15 = IN4004
D2,D9 = LL4148
D10,D11 = BAS40
D3-D8 = BAV99
D12,D13,D14 = LED
IC1 = 68HC11FIFN, programmed, order code **010210-41***
IC2 = 7805

IC3 = LTC485 CN8
IC4 = LM358N
IC5,IC6,IC7 = MOC3020
T1-T6 = BC847

Miscellaneous:

F1 = fuse, 100mA, slow, with PCB mount holder and protective cap
F2 = 100°C thermal fuse (Conrad Electronics #534137)
F3 = 170mA Polyswitch (Conrad Electronics #551198)
F4,F5,F6 = fuse, 6.3A, slow, with PCB mount holder and protective cap
K1 = 3-way PCB terminal block, lead pitch 7.5mm
K3 = 3-way pinheader
K2,K4 = 8-way pinheader
K5 = 10-way pinheader
K6,K7,K8 = 13A panel mounting socket to BS1363
K9 = 5-way pinheader
L1,L2,L3 = toroid suppressor coil, 1.3mH, 4.5A (Conrad Electronics #534366)
TR1 = Mains transformer, 15V, 3.2VA
TRI1,TRI2,TRI3 = BTA26-600A (isolated case!), 600V, 25A, 100mA drive current
X1 = 16MHz quartz crystal 68-way PLCC socket
PCB, order code **010210-1***
* see Readers Services pages and website www.elektor-electronics.co.uk

Ancillaries

K10 = 8-way DIN socket, chassis mount
K11 = 5-way XLR plug (male), chassis mount
K12 = 5-way XLR socket (female), chassis mount
D15,D16,D17 = LED, green
S1,S2,S3 = BCD thumbwheel switch
D18-D29 = IN4148 (solder directly to S1, S2, S3)
P1 = 47kΩ potentiometer, linear
S4 = on/off switch, 1 make contact

tor switch to 'Analogue', which causes the 'Analogue' LED (D17) to go on. Set the code switches to 001 and the LED should stop blinking, if it has not already done so. If a voltage is now applied to analogue channel 1, the lamp connected to outlet 1 should light up; if a voltage is applied to channel 2 the lamp connected to outlet 2 should light up and so on. The code switch determines the channel to which outlet 1 is assigned. For example, if the switch value is set to '3', outlet 1 is assigned to channel 3, outlet 2 to channel 4 and outlet 3 to channel 5. If the channel selection is set to '0' or a value greater than '6', the LED flashes to indicate an error.

Next, connect a DMX signal, which will cause the 'DMX' LED to blink in sync with the DMX transfers. In order to have the lamps be controlled by the DMX signal, you must set the selector switch to the 'DMX' position. The 'Analogue' LED will then go out and the 'DMX' LED will go on. It should now be possible to control the lamp connected to outlet 1 using the DMX channel selected by the code switch, with the outlet 2 being controlled by the next higher channel. If an illegal DMX value ('0' or greater than '512') is selected using the code switch, the 'DMX' LED will flash.

One more tip before you get started: the maximum load per channel is 1 kW. In the *Elektor Electronics* lab, we checked out the functions of the DMX Dimmer using 100-W spotlamps (the maximum load that can be used without fitting the triacs to a heat sink). You should do the same when checking out the unit. Besides this, you should check the temperature of the voltage regulator while testing the operation of the dimmer. If this component becomes too hot, you have no choice but to use a higher-power type or a supplementary heat sink.

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certainly be possible to do so electrically, the necessary insulation using mica washers and plastic screws is **not permissible**. The frames of the thumbwheel switches are fastened to the top of the enclosure, which additionally secures the circuit board. Plastic screws are only allowed to be used if a minimum insulation gap of 3 mm is maintained. You can read more on this subject on the 'Electrical Safety Guidelines' page, which appears regularly in *Elektor Electronics*.

Once everything has been solidly assembled and the mains cable has been fitted using a good strain relief, as shown in the photo, you can start with commissioning. For this, first connect three incandescent lamps. As soon as the mains voltage is applied to the device, at least one LED must go on or start blinking. The brightness of the lamps can now be adjusted from 0 to 100% using the pot. Next, you should connect a voltage source that can be adjusted over the range of 0-10 V and set the selec-

The fourth channel

The circuit of the dimmer is designed such that a four-channel version is possible for four-light bars. The signal for the optional fourth triac output stage is present at PA3 (pin 39) of the microcontroller. The author can provide a circuit diagram and a circuit board layout for the four-channel version.

Interested parties may inquire at:

AKneer@aol.com.